



HEI Research Report 233

Hydrocarbon Extraction and Risk to Groundwater in Pennsylvania: Part 2. An Analysis of Water Quality in the Oldest Hydrocarbon Basin in the United States

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Suuplmentary Appendices A–D

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Contents

Appendix A. Field Methods and Chemical Analysis.....	2
Field Methods	2
Blanks	3
Laboratory Analysis.....	4
Quality Control	5
References.....	6
Appendix B. Community Engagement Plan, Baka 2024.....	7
Appendix C. Wells-Only Statistical Results Tables	11
Table C-1. Regression and Correlation Coefficients for Brine-Related Species’ Concentration vs. Distance (km) to Closest Unconventional Oil and Gas Wells That Are Located Within Hotspot Area (Well Sample Only).....	11
Table C-2. Regression and Correlation Coefficients for Brine-Related Species’ Concentration vs. Distance (km) to Closest Impoundment (Well Sample Only).....	11
Table C-3. Regression and Correlation Coefficients for Brine-Related Species’ Concentration vs. Distance (km) to Closest Spill (Well Sample Only).....	12
Appendix D: Statistical Summary of Entire Groundwater and Spring Dataset.....	13
Table D-1. Statistical Summary of Entire Groundwater and Spring Sample Dataset, Excluding Four Surface Water Samples*	13

Appendix A. Field Methods and Chemical Analysis

Field Methods

At every site, the homeowner was first asked where the well/spring was located, and a visual inspection was conducted. For both spring and well water sources, a pressure tank (small, ~20-gallon tank that pressurizes the water before it enters the house pipes) was located where the water was piped into the house. These tanks often, but not always, have a normal hose spigot at their base. Depending on the water treatment systems, it was sometimes possible to physically bypass the treatments (route water around the system). Some springs are designed with an overflow pipe to release excess water, and they are always flowing. Some houses have a Coyote tank system installed (a proprietary system that pumps water from the well when water is available and the tank is not full, and collects it in a large, ~1,000-gallon tank so that the house draws from the reservoir).

Sampling points were chosen to be located either before any treatment systems or large holding tanks, or at locations where treatment systems were bypassed. Most often, a spigot was available at a pressure tank or between the house and the water source. When the inflow (where water is pumped from the well) into a Coyote tank was accessible, and the well could be triggered to pump, the flow-through bucket was lowered to the inflow point. When sampling at a spring overflow pipe, samples were taken directly from flowing water, with no traditional “purge” possible due to continuous flow. Stream samples were taken directly from the streams. If a property had multiple water sources, we took multiple samples as long as we concluded that the sources were distinct (e.g., a well and a spring on opposite sides of a hill).

When possible, water sources were purged to clear any standing water and to ensure that fresh groundwater was sampled. At the beginning of purging and every 5 minutes during purging, pH, temperature, dissolved oxygen, specific conductance, and temperature (in °C) were measured using a YSI ProDSS multiparameter digital water quality meter with pH/ORP (oxidation-reduction potential), dissolved oxygen (DO), conductivity, and temperature sensors. The probe was submerged in the targeted water in a “flow-through” bucket (5-gallon bucket with a valve installed at the bottom that allows water to cycle while keeping sensors submerged for stability of readings). Water was purged until pH and temperature values stabilized within 5% over a 5-minute interval. At that point, samples were collected. The ProDSS was calibrated daily following the applicable sections in the ProDSS Calibration Guide from YSI.⁵¹ A 2-point calibration was implemented for pH 7 and 10, recalibrating to pH 4 and 7 if necessary for very low pH waters. One-point calibrations were used for SC at 1,000 $\mu\text{S}/\text{cm}$ and for DO using water-saturated air (100%).

The methane concentration in the air was measured using a Bascom-Turner Gas-Rover. The Rover was calibrated before each trip with a 2.5% methane gas mixture from Bascom-Turner; calibration is stable for at least a week. The detection limit was established at 5 ppm methane. The Gas-Rover sensor was held overflowing with water during the purge and around the sampling area; the maximum reading was recorded. No Gas-Rover concentrations were taken at six field sites due to time constraints or device malfunction.

After sufficient purging, the first samples collected were for volatile organic compound (VOC) analysis. They were collected in 20 mL amber glass screw-top headspace vials until a reverse meniscus formed, at which point they were capped with PTFE-lined magnetic screw caps and checked to ensure they contained no gas headspace. Next, samples for major element anions, major element cations, trace metals, and strontium isotopes were collected in acid-washed low-density polyethylene (LDPE) bottles (15 mL, 30 mL, 60 mL, and 60 mL, respectively). Samples for anions, cations, trace metals, and strontium isotopes were filtered using acid-washed syringes and 0.45 μm Nylon syringe filters. All filtered samples except anions were acidified with trace metal-grade nitric acid.

Samples for alkalinity were collected unfiltered and without acidification in 250 mL acid-washed low-density polyethylene (LDPE) bottles. These samples were titrated in the field (within 24 hours) to a pH of 4.2⁵² using a Thermo Scientific Orion field pH meter calibrated daily to pH 4 and 7, and a Hach digital titrator with 1.6 N sulfuric acid cartridges and 100 mL of sample.⁵³

Radon was measured in the field with a DurrIDGE RAD7 radon detector with H₂O attachment. Before collecting into a 250 mL glass bottle, the bottle was triple-rinsed with sample water during purging and then filled carefully in the flow-through bucket to avoid aerating the water and capped while underwater to ensure no headspace. The samples were analyzed with the preprogrammed Sniff and WAT250 testing protocols.⁵⁴ After the data were collected and saved, the system was purged with air for at least 15 minutes to ensure that no residual radon remained that would contaminate the next test. Radon was not measured for stream samples because stream waters lose radon directly to the air.

Samples for dissolved inorganic carbon were collected in 125 mL acid-washed LDPE bottles, submerged carefully in the flow-through bucket after purging was complete to avoid introducing bubbles into the bottle. Bottles were capped underwater, then inverted to check that there was no headspace.

Samples for radium analysis were collected using a 5-gallon bucket with a lid retrofitted with a low-flow pump and column attachments. Twenty liters of purged water were run through approximately 10 g of manganese oxide (MnO) fibers at the rate of less than 1 L/min. Fibers were stored in Ziploc bags for transit. If the pH of the water was below 5, baking soda was added to the water in the 5-gallon bucket to raise the pH above 5 and then filtered with the fibers.

IsoFlasks were filled for dissolved hydrocarbon gas analysis according to IsoTech's sampling protocol.⁵⁵ When sampling from a spring overflow pipe, the top of the IsoFlask connector tubing was held under water to achieve steady flow. When sampling from a stream or bailed sample, a set of connector tubing was adapted to connect to the 5-gallon bucket used for radium sampling (see below), which also produced a steady flow.

After collection, samples were stored on ice until the field team returned to the laboratory, where anion samples were frozen until analysis, while all others except IsoFlasks were stored in a refrigerator held at <40°F. Once sampled, IsoFlasks were stored unrefrigerated and kept flat, as directed by IsoTech.

Blanks

Blanks were collected or analyzed for all analytes except radon, dissolved inorganic carbon, radium, and hydrocarbon gases. The different types of blanks are summarized below.

Process blanks. One process blank per trip was collected for major element anion, major element cation, trace metal, strontium isotope, and alkalinity analyses. For these blanks, deionized (DI) water from the Penn State University Laboratory for Isotopes and Metals in the Environment (PSU LIME) laboratory was used. DI water is water that has been filtered and run through an ion exchange system to remove dissolved constituents. DI water was also taken into the field and was used for rinse water. This DI water was filtered and acidified as if it were a normal sample (or not acidified if analyzed for anions), then submitted for analysis as a process blank with the other samples, using the same bottles, technique, etc.

Trip blanks. One set of trip blanks per trip was taken for the benzene, toluene, ethylbenzene, xylenes (BTEX) analysis. In the PSU LIME laboratory before the trip, a set of cleaned vials was filled with ultra-high purity 0.03-micron filtered organic-free water. These vials were carried in the cooler with the samples during the day, stored in the refrigerator with the samples overnight, and submitted to the laboratory for analysis with each campaign's samples.

Laboratory Analysis

Anion analysis. Fluoride, chloride, sulfate, and bromide were analyzed for all trips at the PSU LIME using a Dionex ICS-2100 Integrated IC System with an IonPac AS18 4×250 mm anion exchange column, an IonPac AG18 4×50 mm guard column, a Dionex Carbonate Removal Device 200-4 mm, and a Dionex EGC III KOH RFIC Eluent Generator Cartridge using manual adjustments of baselines for peak overlap. Early in the project, when no carbonate removal device (CRD) was available in PSU LIME, relatively large carbonate peaks were sometimes observed. The lack of CRD did not affect NO₃ analysis because nitrate shows little to no overlap with carbonate. Samples for F, Cl, SO₄, and Br were held for analysis until a CRD became available.

To check the effects of longer holding times, larger volumes were sampled for trips 3–7, enabling analysis at an additional laboratory where a CRD was available (the Penn State Agricultural Analytical Laboratory (PSU AAL)). These concentrations, reported with precision and accuracy generally better than +1% and +10%, respectively, were completed at holding times <14 days. Following methods as described in the literature,^{56,57} interlab data were compared by ordinary linear regression for a data range likely to have the same measurement error, that is, a subset of at least 10 values selected randomly from within the range where most samples were measured (<1 mg/L (F), <50 mg/L (Cl), <65 mg/L (SO₄), <10 mg/L NO₃)). Only values > limit of quantitation were included. Within 99.9% confidence, the intercepts and slopes did not differ from 0 and 1, respectively, for all anions except bromide.

Given the issues with the bromide analysis, and to analyze concentrations at lower levels than possible at either LIME or AAL (especially where sulfate concentrations create interference), we re-analyzed all the samples between 4 and 9 months after sampling in the Kappe Engineering Laboratory at PSU. These results are reported herein instead of the original analyses for bromide. The analyses of Br at Kappe Engineering Laboratory were completed using a Thermo Fisher Integrion High Pressure Ion Chromatography (HPIC) system with a Dionex IonPac AS18 column and a Dionex CRD. The methodology for analysis is outlined in the IonPac AS18 manual “Isocratic Separation of Anions in 12-Anion Standard.” The method provided a flow rate and eluent concentration for the isolation of bromide from other ion peaks. The method detection limit and reproducibility for bromide are reported as 0.01 mg/L and +/-3%.

Major element analysis. Major elements were measured at PSU LIME using a Thermo iCAP 7400 inductively coupled plasma atomic emission spectroscopy (ICP-AES) system with a 2.5 ppm lutetium (Lu) internal standard. Trace elements were measured at PSU LIME using a Thermo Scientific iCAP TQe Inductively Coupled Plasma Mass Spectrometer (ICP-MS) and iCAP RQ ICP-MS New Wave 193 nm excimer laser.

Sr isotope analysis of the groundwater samples was completed in the Metal Isotopes Laboratory at PSU LIME. Before isotopic analysis, elemental concentration data from the ICP-MS in LIME were used to determine the volume of sample required to attain 1 µg of Sr. This volume of sample was dried down and resuspended in 0.5 mL of 8 N HNO₃ for ion exchange chromatographic separation. Samples were purified chromatographically to isolate the Sr using Eichrom Sr Spec resin. After ion exchange purification, samples were dried down and resuspended in 2 µL of 2 N HNO₃. One µL of the sample volume was loaded onto a single zone-refined rhenium filament with TaCl₅ activator and phosphoric acid. Samples were then loaded onto the turret, with a maximum of 19 samples per reel and two filaments loaded with Sr standard SRM987. The measurement of Sr isotopic composition (⁸⁷Sr/⁸⁶Sr) was collected using the Thermo Scientific Triton Plus TIMS. Repeated analysis of the SRM987 standard resulted in an average ⁸⁷Sr/⁸⁶Sr value of 0.710268 with a standard deviation of 9.9×10^{-6} (n = 13), well within the certified composition of 0.71034 ± 0.000260 .

Dissolved inorganic carbon was analyzed using a Shimadzu TOC-L analyzer at the PSU SALinity with IsoTopeS (SALTS) Laboratory. Samples were filtered into dedicated 40 mL vials to allow for two tests per sample.

Radium was analyzed at PSU SALTS using a Canberra Gamma Ray Spectrometer and Genie 2000 Spectroscopy Software. Two long-lived isotopes of radium (radium-226 and radium-228) were also measured. Briefly, 20 liters of water were collected and then filtered at a rate of <1 liter per minute through MnO-coated fibers. Radium strongly adsorbs to MnO as the water passes through the fibers. Following filtration, the fibers are compressed into a 24 mL vial and sealed for a minimum of 3 weeks until the daughter products of radium can reach secular equilibrium. The total activity of radium-226 and radium-228 is then calculated from energy levels (e.g., 295, 351, and 609 keV (kilo-electron volts) for radium-226 and 239 and 911 for radium-228). Activities are quantified relative to standards with known values and are reported in pCi/L (picocuries per liter).

Gross alpha was the third type of radiological analysis included as part of the project. One hundred mL of water was collected, acidified, and returned to the laboratory. An aliquot of water was then dried and acidified before mixing with a liquid scintillation cocktail. The total alpha disintegrations were then measured using a PerkinElmer Tri-Carb Liquid Scintillation Analyzer. Values are reported in pCi/L. The MnO-coated fibers were sealed in containers for at least 3 weeks before measurement to allow radium daughter products to reach secular equilibrium with the parent radium-226.

BTEX was measured using headspace gas chromatography-mass spectrometry (GC-MS/MS) (EPA method 5021A with application notes from Agilent, Inc.) using a GC-MS/MS system at the Penn State University Energy and Environmental Sustainability Laboratory (PSU EESL). A Trace 1310 GC system (Thermo Fisher Scientific S.p.a., Strand Rivoltana, Km4, 20090, Rodano Milan, Italy) was used, which is connected to a TSQ 9000 – AEI tandem mass spectrometer (Thermo Fisher Scientific, Milan, Italy) and is equipped with an advanced electron impact (AEI) source. The data recorded are processed using Thermo Scientific Dionex Chromeleon 7.2.10 ES Chromatography Data System Version Mus (24543) software. One drop of HCl was added to headspace vials 14 days after sampling if longer holding times were needed. Some samples from trip 1 were not analyzed for BTEX due to a refrigerator malfunction (samples froze and broke the bottles). Stream samples were not analyzed for trip 6 due to budgetary constraints.

Hydrocarbon gas concentrations were quantified by GC at IsoTech Laboratories, Inc.⁵⁸ Samples were analyzed for quantities of dissolved methane, ethane, and propane. Carbon and hydrogen isotopic compositions of gas components were also analyzed, where gas concentrations were high enough, by chromatographic separation followed by combustion and dual-inlet isotope ratio mass spectrometry.⁵⁹ Specifically, those with >1 mg/L of methane were subsequently analyzed for carbon isotope ratios of carbon-13 (¹³C) to carbon-12 (¹²C), called “delta-13-C” ($\delta^{13}\text{C}$), and hydrogen isotope ratios of deuterium (²H or D) to hydrogen (¹H), called “delta-D” (δD) of the methane gas. Samples with >1 mg/L ethane were also analyzed for $\delta^{13}\text{C}$ of ethane when the budget allowed. Stream samples were not analyzed for hydrocarbon gases due to budgetary constraints.

Quality Control

It is well known that detections of analytes can occur in blanks even when the analytes have not been added to the blank sample.⁶⁰ We therefore analyzed concentrations in process blanks for each trip of 25 species using ion chromatography, inductively coupled plasma atomic emission spectroscopy, or inductively coupled plasma mass spectrometry (F, Cl, SO₄, Br, NO₃-NO₃, Al, Ba, Ca, Fe, K, Mg, Mn, Na, P, Si, Sr, Li, Be, Ni, Cu, As, Cd, Tl, Pb, U).

Of the 25 analytes, 12 inorganic species were detected at least once in a process blank over 7 trips. For seven of these (F, Cl, Ca, K, Mg, Na, Si), one to four spurious detections were noted but at much lower concentrations than measured in the lowest-concentration samples from the associated trips. Five of the analytes were detected in the process blanks at concentrations above the lowest concentration in one or more of the associated trips. For sample concentrations that were less than or equal to the

detected concentration in the process blank for the associated trip, we marked the concentration with an asterisk (*) in the results table (NO₃, P, Li, Cu, Pb).

Concentrations of one or more BTEX compounds were detected in trip blanks from all but one of the trips where trip blanks were collected: the maxima for these trip-blank values were 0.39 µg/L for benzene, 3.22 µg/L for toluene, 9.46 µg/L for ethylbenzene, and 12.5 µg/L for total xylenes. This indicates a low-level source of these compounds in the laboratory used for trip deployment. All the sample concentrations were less than the maximum trip-blank value measured for total xylenes, whereas eight water samples showed concentrations within a factor of 2 of the maximum concentrations for BTEX in trip blanks. All the BTEX in the samples were nonetheless far lower than the public health guidelines.⁶¹

Several quality control analyses were calculated following a USGS protocol⁶² with revisions suggested by Csuros.⁶¹ Charge imbalance was calculated as ((sum of cation equivalents – sum of anion equivalents)/(sum of cation equivalents + sum of anion equivalents))*100. Ninety-eight percent of samples were within ±10%, and all were within ±12%. Ion-to-SC ratios were calculated as (sum of cation milliequivalents or sum of anion milliequivalents)/(0.01*SC), with SC as µmhos/cm. Eighty-five percent of samples were within the accepted range of 0.92–1.24 for both ratios. Total dissolved solids (TDS) were calculated as 0.6*[alkalinity] + Na + K + Ca + Mg + Cl + SO₄ + SiO₃ + (NO₃-N) + F, where all concentrations were expressed in mg/L.⁶¹ Sodium/potassium and TDS/SC ratios were within an acceptable range (Na>K if K<10 mg/L and <0.81, respectively) for all samples, with TDS in mg/L and SC in µmhos/cm.⁶² Only the upper bound of the TDS/SC ratio was tested because calculated TDS values can be lower than measured TDS by up to 20%.⁶¹

References

Refer to the References on page 25 in the Investigators' Report.

Appendix B. Community Engagement Plan, Baka 2024

The plan should provide the following information:

- a. Objectives for engagement. Describe how engagement will benefit both the research and members of the community. Include anticipated outcomes of engagement.

The focus groups conducted as part of our first HEI study identified potential water contamination from UOGD wastewater management and associated health risks as a primary concern of communities (Final Report, Chapter 4). Our geoscientific analysis also identified wastewater management as the likely channel for the small but statistically significant increases in Barium and Strontium concentrations found within proximity to UOGD wells (Final Report, Appendix A). In related work, members of our research team identified ‘hotspots’ with small but statistically significant increases in Chloride concentrations in groundwater within proximity to UOGD wells, likely from wastewater mismanagement (Shaheen, Wen et al. 2022). In some of these areas, thallium levels may exceed EPA Safe Drinking Water Standards, using ratio analysis (Shaheen, Wen et al. 2022). Lastly, numerous wastewater spills have been reported to the PA DEP in SWPA in recent years, which may also impair groundwater in the region.

This study aims to sample water from private wells in regions of interest from our previous work in SWPA to confirm/refute our earlier findings and to examine the potential health risks, if any, associated with UOGD. We aim to recruit 100 households near two wastewater impoundment ponds in Washington County (follow-up from the first HEI study), the Chloride hotspots in Washington County (ES&T 2022 paper), and a recent wastewater spill (we are still considering possible sites but likely Greene County).

The study will help address an important community concern: whether their private wells are contaminated, whether UOGD may be linked to contamination, and what health risks, if any, may be associated with contamination exposure.

To date, limited private well testing has been done to examine the links between UOGD, water contamination, and exposures. This study will begin addressing this research gap.

We believe that our study will also help to address other community concerns about a lack of knowledge on the links, if any, amongst UOGD, water, and health. The community health and exposure scientists on our team (Pinto and Bitzer) will conduct a thorough literature review to understand the previously known associations between the materials under study (i.e., barium, strontium, chloride, and other analytes to be tested, as described in our proposal), and health outcomes that will help contextualize the findings to develop outreach materials, which Pinto and Baka will present to communities.

- b. Anticipated community groups and other end users. Describe the anticipated community and end users that the applicants plan to engage or partner and the approach that will be used to identify them. Include the broader context (e.g., historical or social) of efforts by the community or others to address the problem or issue, and how the proposed research will fit into these efforts, including whether the researchers are responding to a community-initiated idea.

We are unaware of previous studies on the relationship amongst energy, water and health in SWPA, although studies by Yale researchers funded by the EPA did study the

relationship, in part, in Northeast PA (Clark, Xiong et al. 2022). Our engagement plan replicates many of the steps of the Yale study outreach; however, uniquely, we have developed ties with community members through our previous focus groups and with community groups in the area that will assist with our recruitment efforts.

We will recruit households for the study in the following ways:

1. We will identify areas of interest from impoundments, hotspots, and a recent spill. We will identify households with private wells within 1km of areas where concentrations were elevated/a spill occurred (treatment group) and households 5–6 km away from the treatment area (control group). We have identified about 400 households in the treatment and control regions.
2. We will review the attendance list of our previous focus groups to identify attendees residing in our study area. We will invite relevant attendees to participate in our study.
3. We will mail a postcard to households in the study groups inviting them to participate in the study. Respondents can sign up via our project website (under construction) or by calling a PSU phone number, which goes to voicemail and will be sent electronically to the PI's email address.
4. We will work with our community partners to call households in our study areas who are also members of their organization. We will provide a list of towns, not names and addresses, to our community partners to maintain data protection.
5. We will work with Penn State Extension to conduct outreach. This will include attending community meetings and door-knocking on dates that will be advertised on the postcard and study website.
6. We will work with our community partners and Penn State Extension to post flyers about our study at local businesses in our target recruitment areas.

We anticipate that we will be able to successfully recruit 100 households to participate in our study through these efforts.

Please also include a letter of collaboration as part of Form F-11 from the collaborators who have an active role in the research. In this letter, the collaborator should describe how they will benefit from and support the study and any past, ongoing, or hoped-for future collaborations with the academic researchers.

Letters of support from our community partners have already been submitted as part of our initial application.

c. Approach to engage community groups and other end users. Describe the strategies and the specific roles of collaborators throughout the study period to conduct constructive community engagement and foster relationships during research. Describe how or if the anticipated community or other end users will be involved in designing, implementing, or communicating the research. Include information on how community members and groups who might play a more active role in the research will be compensated for their time and expenses. Explain the strategy for lowering barriers to participation for historically marginalized communities (e.g., enhance cultural competency, provide multiple engagement opportunities, or provide childcare).

PI Baka will lead the recruitment phase of the research. Pinto will lead community outreach to explain the health-related components of the study and assist with the literature review. PI Baka will also participate in this outreach to assist, as needed. Co-PI Bitzer will lead a literature review

of exposure risks associated with analytes to be studied in the groundwater samples and will help with designing community outreach materials.

We will be going to private homes and will schedule visits with the residents at a time most convenient for them to reduce barriers to participation.

Community partners will help us with recruiting participants, as described above, as well as outreach to promote the study results.

As the study will be of interest to the broader community, we will hold a community meeting and/or webinar to review our results toward the end of the study and attend relevant community events to promote the study findings.

d. Approach for communication of study designs and results. Describe the communication products that you plan to produce (e.g., posters, workshops or manuscripts), intended audiences of those products, and approach to ensuring that research translation and communication of study design, progress, and results occur equitably and through culturally appropriate means.

We will share water testing results with participants and will make members of the study team available to answer any questions that arise. All results will be reviewed by the scientific team, and findings will be provided to all participants via letters that will provide a description of the findings at a 5th-grade reading level.

We will hold three community outreach sessions to share results in person with communities in areas near the study sites. The sessions will be conducted by Pinto with support from Baka and Bitzer as needed. We will host the sessions at venues selected by the community that have the capability for projection of slides and the ability to present and to answer audience questions. Webinars for results will also be provided in coordination with HEI to provide the opportunity for as many community members to engage and ask questions.

We will also share the results of our findings with other community groups in SWPA and ask that they be disseminated to their networks. As a result of HEI-sponsored webinars and focus groups conducted as part of our initial study, PI Baka was invited to give two virtual talks to SWPA community groups. She fielded numerous email inquiries from other community groups because of these engagements. We anticipate similar outcomes from this project.

We will also present the findings at academic conferences and submit journal articles. Copies of these materials will also be provided to community groups.

e. Measures of success. Describe how you will measure progress of the desired outcomes for community engagement based on both outputs and outcomes. Examples of output measures could include the number of workshops and open houses organized, the number of community members participating in meetings, the diversity and range of interests represented at meetings, and the number of communication activities conducted. Other outcome measures would be obtained through surveys provided to stakeholders and the public that capture responses to engagement-related questions and that track changes over

time. If the research consists of a formal partnership between a research institution and community-based organization (defined in Box 2 in [this document](#)), describe mechanisms for feedback and improvement over the course of the research.

We will ensure that all participants receive copies of their water testing results, are invited to talks/events describing the study results and are given access to the study team for follow-up. We will disseminate results via the social networks we have established through the study: NGO groups as well as some active local bloggers who have been following us with interest. The most prominent such blog is the PA Environmental Digest run by the former DEP Secretary, David Hess.

f. Research team member expertise. Describe the team members who have the expertise and responsibility to implement the community engagement plan, including previous experience with community engagement in environmental health research and if those members have received training relevant to equity and equitable relationships with community groups.

Dr. Baka is an energy geographer with expertise in studying UOGD regulatory processes in the US and Canada. She specifically focuses on how stakeholders engage regulatory processes and with what effects. In recent years, she has been researching the emerging petrochemical corridor in Northern Appalachia and has developed extensive ties with community, government, and industry stakeholders. She currently serves on the Steering Committee of the Shale Network Workshop at Penn State and is a member of the Environmental Justice Advisory Board for the Pennsylvania Department of Environmental Protection.

Zachary T. Bitzer, PhD. is an Assistant Professor of Public Health Sciences in the College of Medicine at Pennsylvania State University. Using an interdisciplinary research approach, he focuses on the role of oxidative stress and free radicals catalyzed by metals, generated both endogenously and from environmental exposures, as a mechanism for enhanced susceptibility to exposure-related diseases and cancer. His research also investigates the impact of both endogenous and dietary antioxidants in protection against oxidative stress and its resulting damage, with the goal of designing and developing targeted prevention strategies.

Casey Pinto is a rural Pennsylvania native who grew up in a mining town. She is also a family practice nurse practitioner with 14 years of experience in a variety of settings, including urgent care/fast care, infectious disease/STI and HIV care, and internal medicine. She has extensive experience in rural health disparities, specifically epidemiologic studies examining health outcomes related to public health, including cancer, sexually transmitted infections, and opioid use disorder. She also has extensive experience communicating findings to lay audiences at both the individual level as a provider and at the population level, where she has engaged in many public interviews for local newspapers and radio stations about current public health concerns (COVID-19, Mpox, etc.).

References

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Appendix C. Wells-Only Statistical Results Tables

Table C-1. Regression and Correlation Coefficients for Brine-Related Species' Concentration vs. Distance (km) to Closest Unconventional Oil and Gas Wells That Are Located Within Hotspot Area (Well Sample Only)

	SC	Na	Cl	Ba	SO ₄	Sr	Br	Fe	CH ₄	Ra-226	Ra-228	Rn
OLS_slope	3.401 (0.684, $R^2 = 0.047$)	3.078 (0.073, $R^2 = 0.207$)	-0.100 (0.962, $R^2 = -0.006$)	0.004 (0.409, $R^2 = 0.096$)	-0.596 (0.313, $R^2 = -0.117$)	-0.006 (0.458, $R^2 = -0.086$)	0.013 (0.241, $R^2 = 0.136$)	0.002 (0.727, $R^2 = 0.041$)	0.217 (0.052, $R^2 = 0.224$)	0.001 (0.718, $R^2 = 0.042$)	0.002 (0.509, $R^2 = 0.077$)	-10.272 (0.341, $R^2 = -0.113$)
Spearman	-0.066 (0.574)	0.027 (0.816)	-0.050 (0.669)	0.060 (0.606)	-0.172 (0.138)	-0.102 (0.382)	0.112 (0.337)	0.090 (0.442)	0.318* (0.005)	0.139 (0.230)	0.076 (0.516)	-0.175 (0.138)
Kendall's tau	-0.044 (0.578)	0.028 (0.716)	-0.037 (0.635)	0.038 (0.634)	-0.106 (0.176)	-0.062 (0.427)	0.071 (0.365)	0.064 (0.476)	0.218* (0.006)	0.099 (0.206)	0.055 (0.484)	-0.119 (0.136)
ATS slope	-2.638 (0.578)	0.191 (0.716)	-0.258 (0.635)	0 (0.634)	-0.573 (0.176)	-0.005 (0.427)	3.00×10^{-4} (0.365)	0 (0.476)	2.28×10^{-4} * (0.006)	0.002 (0.206)	0.002 (0.484)	-9.278 (0.136)

Note: P values and R^2 values are reported in parentheses following each coefficient; asterisks indicate statistically significant features at the significance level of 95%; bold font highlights statistically significant negative correlations, indicating that a contaminant increases near the feature.

Table C-2. Regression and Correlation Coefficients for Brine-Related Species' Concentration vs. Distance (km) to Closest Impoundment (Well Sample Only)

	SC	Na	Cl	Ba	SO ₄	Sr	Br	Fe	CH ₄	Ra-226	Ra-228	Rn
OLS_slope	13.670 (0.123, $R^2 = 0.178$)	4.994* (0.006, $R^2 = 0.314$)	2.039 (0.362, $R^2 = 0.106$)	0.008 (0.080, $R^2 = 0.202$)	0.122 (0.848, $R^2 = 0.022$)	-0.006 (0.503, $R^2 = -0.078$)	0.031* (0.006, $R^2 = 0.311$)	-0.002 (0.709, $R^2 = -0.044$)	0.103 (0.394, $R^2 = 0.099$)	-5.48×10^{-5} (0.984, $R^2 = -0.002$)	-0.000 (0.984, $R^2 = -0.002$)	-17.963 (0.111, $R^2 = -0.188$)
Spearman	-0.005 (0.967)	0.087 (0.455)	-0.074 (0.524)	-0.102 (0.382)	0.055 (0.635)	-0.261* (0.023)	-0.018 (0.875)	-0.205 (0.075)	0.103 (0.374)	-0.170 (0.142)	-0.197 (0.088)	-0.110 (0.356)
Kendall's tau	0.001 (0.993)	0.057 (0.465)	-0.039 (0.615)	-0.067 (0.398)	0.046 (0.560)	-0.172* (0.028)	-0.016 (0.837)	-0.156 (0.082)	0.059 (0.458)	-0.129 (0.099)	-0.137 (0.080)	-0.072 (0.368)
ATS slope	0 (0.993)	0.373 (0.465)	-0.213 (0.615)	-0.001 (0.398)	0.269 (0.560)	-0.019* (0.028)	-6.42×10^{-5} (0.837)	0 (0.082)	2.04×10^{-5} (0.458)	-0.004 (0.099)	-0.005 (0.080)	-5.574 (0.368)

Note: P values and R^2 values are reported in parentheses following each coefficient; asterisks indicate statistically significant features at the significance level of 95%; bold font highlights statistically significant negative correlations, indicating that a contaminant increases near the feature.

Table C-3. Regression and Correlation Coefficients for Brine-Related Species' Concentration vs. Distance (km) to Closest Spill (Well Sample Only)

	SC	Na	Cl	Ba	SO ₄	Sr	Br	Fe	CH ₄	Ra-226	Ra-228	Rn
OLS_slope	-19.252 (0.233, $R^2 = -0.139$)	-6.885* (0.038, $R^2 = -0.239$)	-4.563 (0.259, $R^2 = -0.131$)	-0.017* (0.043, $R^2 = -0.233$)	1.231 (0.283, $R^2 = 0.125$)	-0.012 (0.422, $R^2 = -0.094$)	-0.031 (0.145, $R^2 = -0.169$)	-0.006 (0.447, $R^2 = -0.089$)	-0.335 (0.123, $R^2 = -0.178$)	-0.004 (0.379, $R^2 = -0.102$)	-0.005 (0.301, $R^2 = -0.120$)	8.716 (0.520, $R^2 = 0.077$)
Spearman	-0.022 (0.849)	-0.322* (0.005)	-0.066 (0.572)	-0.138 (0.236)	0.212 (0.066)	-0.054 (0.646)	-0.095 (0.412)	0.040 (0.729)	-0.314* (0.006)	-0.123 (0.290)	-0.145 (0.211)	0.044 (0.713)
Kendall's tau	-0.016 (0.837)	-0.221* (0.005)	-0.047 (0.548)	-0.094 (0.239)	0.146 (0.062)	-0.041 (0.606)	-0.067 (0.394)	0.028 (0.754)	-0.215* (0.007)	-0.082 (0.294)	-0.100 (0.203)	0.032 (0.693)
ATS slope	-0.987 (0.837)	-1.640* (0.005)	-0.324 (0.548)	-0.002 (0.239)	1.247 (0.062)	-0.006 (0.606)	-3.84×10^{-4} (0.394)	0 (0.754)	-2.41×10^{-4}* (0.007)	-0.002 (0.294)	-0.003 (0.203)	2.785 (0.693)

Note: P values and R^2 values are reported in parentheses following each coefficient; asterisks indicate statistically significant features at the significance level of 95%; bold font highlights statistically significant negative correlations, indicating that a contaminant increases near the feature.

Appendix D: Statistical Summary of Entire Groundwater and Spring Dataset

Table D-1. Statistical Summary of Entire Groundwater and Spring Sample Dataset, Excluding Four Surface Water Samples*

Analyte	Unit	<i>n</i>	Min	Max	Mean	Median	5th Percentile	25th Percentile	75th Percentile	95th Percentile	MCL/SMCL	% Exceeding MCL/SMCL
DO	mg/L	90	0.278	9.92	3.955	2.975	0.336	0.669	7.167	9.103	–	–
SC	μS/cm	90	230	3485	782.881	658	428.635	556.25	816.75	1,580.8	–	–
pH	pH	90	6.05	8.99	7.135	7.04	6.564	6.885	7.278	8.046	6.5–8.5 ^b	8.9% (8)
Alkalinity	mg CaCO ₃ /L	79	43	668	272.746	265	170.13	224.5	304.5	443	–	–
Air [CH ₄]	ppm, max	83	5	132	8.241	5	5	5	5	15.9	–	–
F	mg/L	90	0.04	3.52	0.281	0.114	0.057	0.088	0.186	1.331	2 ^b	1.1% (1)
Cl	mg/L	90	0.684	697	61.616	16.4	2.12	6.498	67.65	254.95	250 ^b	5.6% (5)
SO ₄	mg/L	90	0.06	225	40.313	32.6	9.493	23.525	44.15	95.975	250 ^b	0.0% (0)
Br	mg/L	89	0.014	5.813	0.125	0.033	0.021	0.027	0.054	0.164	2 ^d	1.1% (1)
NO ₃ -NO ₃	mg/L	90	0.038	27.8	3.653	1.515	0.108	0.3	6.095	12.27	44 ^a	0.0% (0)
Al	mg/L	90	0.01	0.02	0.011	0.01	0.01	0.01	0.01	0.02	0.05–0.2 ^b	0.0% (0)
Ba	mg/L	90	0.04	2.05	0.17	0.13	0.05	0.082	0.16	0.31	2 ^a	1.1% (1)
Ca	mg/L	90	0.67	295	84.24	84.3	6.81	56.65	105.5	159.45	–	–
Fe	mg/L	90	0.005	2.12	0.058	0.005	0.005	0.005	0.005	0.196	0.3 ^b	4.4% (4)
K	mg/L	90	0.03	7.01	1.989	1.855	0.833	1.368	2.56	3.536	–	–
Mg	mg/L	90	0.31	53.7	16.02	14.85	2.228	10.325	20.375	31.265	–	–
Mn	mg/L	90	0.005	0.43	0.036	0.005	0.005	0.005	0.03	0.195	0.05 ^b	16.7% (15)
Na	mg/L	90	2.04	622	54.885	15.4	3.436	6.695	57.1	241.35	–	–
P	mg/L	90	0.01	0.29	0.028	0.02	0.01	0.01	0.02	0.07	–	–
Si	mg/L	90	1.05	9.62	5.571	5.32	3.474	4.772	6.212	8.402	–	–
Sr	mg/L	90	0.1	2.14	0.609	0.46	0.14	0.32	0.678	1.648	4 ^c	0.0% (0)

Analyte	Unit	<i>n</i>	Min	Max	Mean	Median	5th Percentile	25th Percentile	75th Percentile	95th Percentile	MCL/ SMCL	% Exceeding MCL/SMCL
Li	µg/L	90	0.27	61.9	11.152	9.86	3.396	6.475	13.175	20.195	10 ^f	48.9% (44)
Be	µg/L	90	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	4 ^a	0.0% (0)
Ni	µg/L	90	0.05	2.19	0.378	0.275	0.06	0.162	0.46	1.126	100 ^e	0.0% (0)
Cu	µg/L	90	0.05	23.2	3.5	2.41	0.059	0.7	4.828	9.772	1,000 ^b	0.0% (0)
As	µg/L	90	0.05	3.58	0.304	0.11	0.05	0.05	0.188	1.537	10 ^a	0.0% (0)
Cd	µg/L	90	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	5 ^a	0.0% (0)
Tl	µg/L	90	0.05	1.54	0.091	0.05	0.05	0.05	0.05	0.21	2 ^a	0.0% (0)
Pb	µg/L	90	0.05	1.59	0.271	0.185	0.05	0.07	0.358	0.694	15 ^a	0.0% (0)
U	µg/L	90	0.05	0.97	0.311	0.26	0.05	0.07	0.478	0.735	30 ^a	0.0% (0)
87Sr/86Sr	–	80	0.7111	0.7131	0.7118	0.7117	0.7113	0.7115	0.7121	0.7128	–	–
Benzene	µg/L	84	0.04	0.77	0.113	0.04	0.04	0.04	0.045	0.549	5 ^a	0.0% (0)
Toluene	µg/L	84	0.04	3.29	0.432	0.04	0.04	0.04	0.122	3.103	1,000 ^a	0.0% (0)
Ethylbenzene	µg/L	84	0.04	9.49	1.263	0.04	0.04	0.04	0.11	9.21	700 ^a	0.0% (0)
m,p-Xylene	µg/L	84	0.08	0.954	0.105	0.08	0.08	0.08	0.08	0.15	10,000	0.0% (0)
o-Xylene	µg/L	84	0.06	0.464	0.074	0.06	0.06	0.06	0.06	0.117	10,000	0.0% (0)
Xylene(total)	µg/L	84	0.14	1.418	0.179	0.14	0.14	0.14	0.14	0.267	10,000 ^a	0.0% (0)
Methane	mg/L	89	0	57	1.195	0.001	0	0	0.009	5.48	10 ^g	3.4% (3)
Ethane	mg/L	89	0	0.58	0.016	0	0	0	0	0.032	–	–
Propane	mg/L	89	0	0.005	0	0	0	0	0	0	–	–
δ13C₁	–	8	–77.16	–51.5	–66.498	–65.535	–76.145	–71.2	–64.108	–55.7	–	–
δDC₁	–	8	–219.3	–153.9	–191.913	–196.55	–213.945	–202.725	–184.675	–161.18	–	–
δ13C₂	–	1	–35.2	–35.2	–35.2	–35.2	–35.2	–35.2	–35.2	–35.2	–	–
Rn	pCi/L	86	3.74	2760	324.719	220	20.525	68.375	408.25	979.25	300 ^e	38.4% (33)
Ra-226	pCi/L	90	0.028	1.046	0.142	0.096	0.035	0.058	0.162	0.38	27 ^h	0.0% (0)
Ra-228	pCi/L	90	0.016	0.864	0.176	0.138	0.036	0.089	0.216	0.472	2.7 ^h	0.0% (0)
Ra 226+228	pCi/L	90	0.055	1.366	0.318	0.24	0.083	0.143	0.387	0.876	5 ^a	0.0% (0)

Analyte	Unit	<i>n</i>	Min	Max	Mean	Median	5th Percentile	25th Percentile	75th Percentile	95th Percentile	MCL/SMCL	% Exceeding MCL/SMCL
228Ra/226Ra	–	90	0.235	3.23	1.419	1.37	0.5	1.046	1.724	2.53	–	–

*Data sources for maximum contaminant level (MCL), secondary contaminant level (SMCL), or other guidance values are indicated via superscript letters below:

^a National Primary Drinking Water Regulations, United States Environmental Protection Agency, updated 9 Oct. 2024, www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

^b Drinking Water Secondary Standards: Guidance for Nuisance Chemicals, United States Environmental Protection Agency, updated 14 Jun. 2024, <https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals>.

^c National Recommended Water Quality Criteria - Human Health Criteria Table, United States Environmental Protection Agency, updated 24 Sep. 2024, <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table>.

^d Ambient Surface Water Quality Standards Documentation, United States Environmental Protection Agency, 18 Dec. 1984, https://www.epa.gov/sites/default/files/2015-06/documents/ny_hh_755_w_07241985.pdf.

^e 2018 Edition of the Drinking Water Standards and Health Advisories Table, United States Environmental Protection Agency, Mar. 2018, <https://www.epa.gov/system/files/documents/2022-01/dwtable2018.pdf>.

^f Smith, C.D. and Nowell, L.H., 2024. Health-Based Screening Levels for evaluating water-quality data (3rd ed.). U.S. Geological Survey web page, accessible at <https://water.usgs.gov/water-resources/hbsl/>.

^g Eltschlager, K. K., Hawkins, J. W., Ehler, W. C., and Baldassare, F., Technical Measures for the Investigation and Mitigation of Fugitive Methane Hazards in Areas of Coal Mining, United States Department of the Interior, Office of Surface Mining, Sep. 2001, <https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2002106133.xhtml>.

^h World Health Organization. (2022). Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First and Second Addenda. Geneva: World Health Organization. Available at: [World Health Organization Repository](https://www.who.int/publications-detail/9789240049818).